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EPA

Indoor Air – Assessment

Methods of Analysis for Environmental Carcinogens

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Methods of Analysis for Environmental Carcinogens

Environmental Criteria and Assessment Office
Office of Health and Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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PREFACE

In October 1986 Congress passed the Superfund Amendments and Reauthorization Act (SARA, PL 99-499) that includes Title IV – The Radon Gas and Indoor Air Quality Research Act. The Act directs that EPA undertake a comprehensive indoor air research program.

Research program requirements under Superfund Title IV are specific. They include identifying, characterizing, and monitoring (measuring) the sources and levels of indoor air pollution; developing instruments for indoor air quality data collection; and studying high-risk building types. The statute also requires research directed at identifying effects of indoor air pollution on human health. In the area of mitigation and control the following are required: development of measures to prevent or abate indoor air pollution; demonstration of methods to reduce or eliminate indoor air pollution; development of methods to assess the potential for contamination of new construction from soil gas, and examination of design measures for preventing indoor air pollution. EPA's indoor air research program is designed to be responsive in every way to the legislation.

In responding to the requirements of Title IV of the Superfund Amendments, EPA-ORD has organized the Indoor Air Research Program around the following categories of research: A) Sources of Indoor Air Pollution; B) Building Diagnosis and Measurement Methods; C) Health Effects; D) Exposure and Risk (Health Impact) Assessment; and E) Building Systems and Indoor Air Quality Control Options.

EPA is directed to undertake this comprehensive research and development effort not only through in-house work but also in coordination with other Federal agencies, state and local governments, and private sector organizations having an interest in indoor air pollution.

The ultimate goal of SARA Title IV is the dissemination of information to the public. This activity includes the publication of scientific and technical reports in the areas described above. To support these research activities and other interests as well, EPA publishes its results in the INDOOR AIR report series. This series consists of five subject categories: Sources, Measurement, Health, Assessment, and Control. Each report is printed in a limited quantity. Copies may be ordered while supplies last from:

U.S. Environmental Protection Agency
Center for Environmental Research Information
26 West Martin Luther King Drive
Cincinnati, OH 45268

When EPA supplies are depleted, copies may be ordered from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

ABSTRACT

This monograph describes, in a general way, published sampling procedures and analytical approaches for known and suspected carcinogens. The primary focus is upon carcinogens found in indoor air, although the methods described are applicable to other media or environments. In cases where there are no published methods for a particular pollutant in indoor air, methods developed for the workplace and for ambient air are included since they should be adaptable to indoor air.

Known and suspected carcinogens have been grouped into six categories for the purposes of this and related work. The categories are radon, asbestos, organic compounds, inorganic species, particles, and non-ionizing radiation. Some methods of assessing exposure that are not specific to any particular pollutant category are covered in a separate section.

This report is the fifth in a series of EPA/Environmental Criteria and Assessment Office Monographs. The series includes the following titles:

I. DEVELOPMENT OF A RISK CHARACTERIZATION FRAMEWORK

II. A REVIEW OF INDOOR AIR QUALITY RISK CHARACTERIZATION STUDIES

III. USE OF BENZENE MEASUREMENT DATA IN RISK CHARACTERIZATION ESTIMATES: A PRELIMINARY APPROACH

IV. INDOOR CONCENTRATIONS OF ENVIRONMENTAL CARCINOGENS

V. METHODS OF ANALYSIS FOR ENVIRONMENTAL CARCINOGENS

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INTRODUCTION

Indoor air compounds with carcinogenic activity in animals, humans, or both include radon, asbestos, organic compounds, inorganic compounds, particles (including environmental tobacco smoke or ETS), and non-ionizing radiation (NIR). Some of the pollutants in this list exist as vapors, some as fibers or particulate material, some are adsorbed onto suspended particulate material, and some are distributed between a vapor-phase and a particle-bound state. Some classes contain a large number of compounds (ETS and organics), one is associated with a single parent element (radon); and one is not a chemical species at all (NIR). Most are dangerous in themselves but one (radon) is a precursor to even more deadly progeny. Because of these differences in physical and chemical states and properties, each carcinogen class generally requires different sampling and analysis approaches.

As a further complication, a single indoor environment may contain a wide variety of air pollutant mixtures. No single best approach currently exists for assessing the composition and concentrations of such complex mixtures. There are many uncertainties inherent in characterizing the pollutant mix of indoor environments and there is great difficulty in predicting the severity and nature of toxicological interactions.

Identical mixtures of pollutants from different sampling sites are rarely, if ever, encountered in indoor air. Similar mixtures may be found in a variety indoor environments, but with concentrations of individual components differing significantly. For example, ETS may contain 4,500 individual compounds, each present at a concentration that depends upon a wide variety of factors. Therefore, from a practical sampling and analysis point of view, only the most toxic of the compounds or the pollutants making up the largest portions of the mixture can be measured.

The analytical methods presented below are classified by pollutant category with sub-categories added as deemed appropriate. The purpose of this monograph is to present an overview of some common methods for each category of pollutant or, in some cases, for specific pollutants. While the list of methods for each category is not exhaustive, significant effort was expended to include at least one or two workable methods for each category.

RADON

OVERVIEW

Sampling and analysis of radon and radon progeny (decay products) in indoor air are complicated by both spatial and temporal changes in concentration. An acceptable measurement scheme must also take into account diurnal and seasonal variations.

In addition, analysis is complicated by dramatic changes in composition of a collected sample with time. The change in composition is due to the radioactive decay of both radon and its progeny. Radon decays more slowly (half-life 3.83 days) than any of its progeny but still at a fast enough rate to require that analyses be made very soon after samples are taken (Cothern and Smith, 1987). New methodologies to measure time-integrated radon concentrations on indoor glass surfaces (such as picture glass) are under development and appear promising for long term human exposure studies (Samuelsson, 1988).

SAMPLING

Collection of samples may be accomplished by grab sampling, continuous sampling, or integrative sampling. Grab sampling involves the taking of essentially an instantaneous sample and allows determination of the concentration at the specific time the sample was taken. Continuous sampling involves the taking of many measurements at closely spaced time intervals and allows the determination of patterns in the variation of concentration over the entire sampling time. Integrative sampling involves the taking of a single sample over a long time interval and allows determination of a single average concentration over the sampling period (Cothern and Smith, 1987).

Radon may be separated from its progeny during sampling, and the concentration of either or both determined by analysis. The separation is typically accomplished by allowing radon to diffuse through a passive barrier (e.g., foam rubber). Radon progeny, which rapidly adsorb onto the surfaces of airborne particulates and other solids, cannot pass through such barriers.

ANALYSIS

Most of the analytical methods for radon and radon progeny actually measure emitted radiation and not concentration of the target species, although the two are directly related in the absence of other radioactive material. The decay chain for radon and its progeny is summarized in Table 1. The decay sequence includes the emission of three fundamental kinds of radioactivity: Alpha particles, beta particles, and gamma rays. The emission rate of any or all of these may be measured with appropriate instrumentation (Cothern and Smith, 1987).

Concentrations of radon are usually expressed in bequerels per cubic meter (Bq/m^3) or in picocuries per liter (pCi/L). One bequerel equals 1 event per second (decay/s) and one picocurie equals 0.037 bequerel.

Radon progeny concentrations are usually expressed in working level months (WLM). One working level equals the quantity of short-lived progeny that will result in 1.3×10^5 MeV of potential alpha energy per liter of air. Potential alpha energy is used to relate atmospheric concentration of radon progeny to dose delivered to the human lung. It represents the total alpha energy an atom can emit as it decays through its entire radioactive series, and it must be calculated from measurements (or estimates) of the concentrations of the progeny.

Although a large number of devices are available, the actual analysis for radon and/or its progeny is typically accomplished using a scintillation phosphor mounted on a photomultiplier, an ionization chamber, a thermoluminescent dosimeter (TLD), or a visual or automatic image-processing method. Table 2 provides a summary of currently available radon measurement devices based on instrument type.

Scintillation devices include cells for gaseous and liquid samples and plates for samples of radon progeny collected on filters. Gas scintillation cells and scintillation plates are typically coated with zinc sulfide; in liquid scintillation cells, the liquid contains both the radioactive material and the scintillator. In all cases, the intensity of the light pulses generated by the impingement of radioactive particles (alpha, beta, and/or gamma) on the scintillating material is measured with the aid of a photomultiplier tube (Cothern and Smith, 1987; Henschel, 1988).

An ionization chamber may be used to measure radon in air. The current in the chamber is directly proportional to the radon concentration (Cothern and Smith, 1987).

TABLE 1. RADON-222 DECAY SERIES

Isotope	Symbol	Decay Mode	Half-Life
Radon-222	$^{222}_{86}Rn$		2.82 days
	↓	Alpha ($^{4}_{2}He$)	
Polonium-218*	$^{218}_{84}Po$		30.5 min
	↓	Alpha ($^{4}_{2}He$)	
Lead-214*	$^{214}_{82}Pb$		26.8 min
	↓	Beta ($^{0}_{-1}e$)	
Bismuth-214*	$^{214}_{83}Bi$		19.7 min
	↓	Beta ($^{0}_{-1}e$)	
Polonium-214*	$^{214}_{84}Po$		0.000164 sec
	↓	Alpha ($^{4}_{2}He$)	
Lead-210	$^{210}_{82}Pb$		21 years
	↓	Beta ($^{0}_{-1}e$)	
Bismuth-210	$^{210}_{83}Bi$		5 days
	↓	Beta ($^{0}_{-1}e$)	
Polonium-210	$^{210}_{84}Po$		138 days
	↓	Alpha ($^{4}_{2}He$)	
Lead-206	$^{206}_{82}Pb$		Stable

*Radon progeny of primary concern.

A thermoluminescent dosimeter (TLD) may be used to provide an integrated measurement of radon or radon progeny activity. The TLD chip is typically lithium fluoride or calcium fluoride (Cothern and Smith, 1987).

In the two-filter method, a small tube, 30-100 cm long, is equipped with two filters: An entrance filter, which removes progeny from the sample as it is drawn into the tube, and an exit filter, which traps the polonium-218 formed by the decay of some of the radon atoms

TABLE 2. APPLICATIONS AND SENSITIVITIES OF SOME RADON MEASUREMENT DEVICES

Instrument type	Application	Sensitivity[a]	Purpose[b]
Direct measurement			
Scintillation cell	Grab or continuous	3.7 Bq/m^3[c]	Screening, diagnostic
Ionization chamber	Grab or continuous	3.7 Bq/m^3[c]	Screening, diagnostic
Passive barrier method[d]			
Scintillator	Continuous	3.7 Bq/m^3[c]	Screening, diagnostic
TLD chip	Integrating	0.08-8.1 Bq/m^3	Screening, large scale survey
Two-filter method	Grab or continuous	3.7 Bq/m^3[c]	Diagnostic
Passive sampling devices			
Activated charcoal	Integrating	7.4 Bq/m^3 for 100-hour exposure	Screening, large scale survey
Alpha track	Integrating	18.5 Bq/m^3 for 30-day exposure[c]	Screening, large scale survey

[a] With collection of progeny on (or in close proximity to) a scintillator or thermoluminescent detector (TLD) chip.

[b] Adapted from Cothern & Smith (1987). 1 pCi/L = 37 Bq/m^3.

[c] A sensitivity less than the value shown is generally achievable depending on the specific instrument used.

[d] Three typical purposes are illustrated:

- Screening: The aim of a screening method is to evaluate rapidly and inexpensively where high radon concentrations may occur.
- Diagnostic: Designed to measure specific parameters for detailed radon analysis such as:
  - short-term spatial and temporal variations,
  - relationship with other factors (such as ventilation rate),
  - equilibrium fraction of each of the radon daughters,
  - effect of remedial actions.
- Large-scale survey: A national, regional or other large study aimed at evaluating the exposure of the public. A large number of time-averaged measurements are needed.

as they move through the tube. After sampling, the filter is removed and counted by measurement of the alpha decays. The method has been adapted to continuous and integrative monitoring through the use of a TLD chip at the exit filter (Cothern and Smith, 1987).

Radon may be collected from air by adsorption onto the surface of activated charcoal. It may be analyzed by de-emanation of the radon from the charcoal into a scintillation cell and alpha-counting; by heating the charcoal and counting gamma emissions from the desorbed radon using a sodium iodide system; or by dissolving the charcoal in liquid scintillation fluid and counting in a liquid scintillation detector (Cothern and Smith, 1987).

In an alpha track detector, a thin piece of an appropriate plastic is placed in a holder and exposed to air containing radon (and perhaps its progeny) for an extended period of time (up to a year). During the exposure period, alpha particles, emitted by decaying nuclei, strike the surface of the plastic making microscopic gouge marks or alpha tracks. The exposed plastic is removed from its holder and chemically etched to enlarge the tracks. The alpha tracks, now appearing as small holes on the surface, are then visually counted using a wide-screen microscope (Cothern and Smith, 1987) or some other counting system (e.g., spark counter, CCD camera, etc.).

The principles used for the measurement of radon progeny are similar to those used to measure radon, but the sampling and analysis approach must be altered significantly. Radon progeny may be removed by passing the air sample through a filter. Radon gas passes through such a barrier while the progeny, which are adsorbed onto suspended particulate material, are collected on the filter.

The early methods for measuring radon progeny were based on the method originally reported by Kusnetz (1956) and Tsviglou et al. (1953). The progeny, which are largely attached to aerosols, are collected on a filter and subsequently analyzed by alpha-particle spectroscopy. This allows the determination of the activity of each progeny on the filter and the subsequent computation of the potential alpha energy or working level concentration.

Both passive and active alpha track detection have been applied to the measurement of radon progeny. Unfortunately, while progeny are easily excluded from the analysis for radon by this method, radon is not easily excluded from the analysis for progeny. The typical approach is to measure radon-plus-progeny, then radon only, and subtract to get the progeny-only value.

Programs designed to assist commercial firms offering radon measurement services have been established in many countries. In the United States, the Environmental Protection Agency (U.S. Environmental Protection Agency) supports a National Radon Measurement Proficiency (RMP) Program (U.S. Environmental Protection Agency, 1988). Each company participating in the National RMP Program submits passive detectors for exposure in a chamber containing a known concentration of radon or, in the case of continuous or active monitors, carries the device(s) to the chamber and samples the contaminated air directly through a port. After exposure, the passive detectors are returned to the company for analysis. The company reports its measured values for all detectors and/or monitors to the RMP Program Coordinator. The RMP Program currently uses the mean of the absolute value of the relative error (MARE) to evaluate the company's performance with a particular device or type of detector. The company is judged proficient at measurement if its MARE is 0.25 or less. The results of the RMP Program provide useful information on the relative accuracy of methods used to sample and measure radon and radon progeny in indoor air. Table 3 summarizes the results of the most recent proficiency measurement round for which published data are available (Singletary, 1988).

TABLE 3. RESULTS FROM ROUND 5 OF THE RADON MEASUREMENT PROFICIENCY PROGRAM[a]

Species Method	Number[b] of sets	Range of target values	Median error[c] (%)	Relative standard deviation (%)
Radon				
Alpha track detectors	9	170 to 2000 Bq/m^3	18	24
Charcoal canisters	223	160 to 1900 Bq/m^3	12	18
Continuous monitors	88	220 to 1400 Bq/m^3	11	12
Grab sampling	60	420 to 3700 Bq/m^3	13	12
Electret-PERM	97	170 to 2000 Bq/m^3	18	20
Radon progeny				
Continuous working-level monitors	70	0.02 to 0.15 WL[d]	11	171[e]
Grab working-level sampling	48	0.01 to 0.21 WL	19	13
Radon progeny integrating sampling unit (RPISU)	4	0.04 to 0.07 WL	14	36

[a]Based on Gearo et al. (1988) and Research Triangle Institute (1988).
[b]Each set consists of 4 separate measurements.
[c]Median of the Absolute Relative Error
[d]1 Working level, WL, ($\approx 2.08 \times 10^{-5}$ J/M^3) = The potential alpha energy concentration of progeny in equilibrium with a radon concentration of 3700 Becquerels per cubic meter (Bq/m^3).
[e]Large standard deviation was primarily due to two sets of data with enormous absolute relative error.

ASBESTOS

OVERVIEW

Very few studies have been made of asbestos in homes. This section contains analytical methods used to measure airborne asbestos in the workplace and in post-abatement situations. The same methods can, in principle, be applied to asbestos in homes.

Because of their small size, airborne asbestos fibers are difficult to distinguish from other man-made and natural fibers. Fibers are usually collected on either a cellulose ester filter or a polycarbonate filter and measured visually under relatively high magnification, using phase contrast microscopy (PCM), scanning electron microscopy (SEM), or transmission electron microscopy (TEM). All three methods require the visual counting of fibers in randomly selected grid sections of slides prepared from the collected material. The key features of PCM, SEM, and TEM are shown in Table 4.

PHASE CONTRAST MICROSCOPY

The standard protocol for measuring exposure to airborne asbestos in the industrial workplace adopted by the Occupational Safety and Health Administration (OSHA) specifies PCM as the analytical method. The method (NIOSH 7400) specifies a 25-mm diameter, 0.8 to 1.2 μm pore size cellulose ester membrane filter for collection. Microscope slides are prepared from the collected material and the fibers in randomly chosen regions of each slide are counted using a positive phase contrast microscope with a 100 μm diameter graticule. One of two sets of counting rules are used to define which fibers are counted. The "A" Rules require that only fibers longer than 5 μm and with an aspect ratio (length to diameter) greater than or equal to 3:1 be counted. The "B" Rules require that only the ends of fibers longer than 5 μm and less than 3 μm in diameter and with an aspect ratio equal to or greater than 5:1 be counted. The final fiber count for the B Rules is determined by dividing the number of ends by 2. Fiber density on the filter is reported in fibers/mm^2; fiber concentration in the original air sample is reported in fibers/mL (Eller, 1984).

There are two serious limitations in the protocols described above. The first limitation is that PCM cannot distinguish between asbestos and non-asbestos fibers; all fibers or elongated

TABLE 4. COMPARISON OF PCM, SEM, AND TEM[a]

	PCM	SEM	TEM
Specificity for asbestos	Not specific (all fibers > 5 μm long are counted)	More specific but not definitive	Definitive (with options)
Magnification	400	1000-2000	20000
Sensitivity (thinnest fiber visible)	0.15 μm (best) 0.25 μm (typical)	0.05 μm (best) 0.20 μm (typical)	0.0002 μm (best) 0.0025 μm (typical)

[a]From U.S. Environmental Protection Agency (1985b). See text for definitions of PCM, SEM, TEM.

particles that meet the length, diameter, and aspect ratio criteria are counted. The second limitation is a result of the optical magnification used in PCM: Only fibers or particles 0.25 μm in diameter or larger can be seen (U.S. Environmental Protection Agency, 1985b).

SCANNING ELECTRON MICROSCOPY (SEM)

Scanning electron microscopy (SEM) is more sensitive to thin fibers and has a better specificity for asbestos than PCM. Fibers are typically collected on a 0.4 to 0.8 μm pore size polycarbonate (or cellulose ester) filter, carbon-coated directly on the filter, and transferred to an EM grid. The fiber substrate is relatively thick and the electrons bombarding the specimen during visual analysis are scattered and reflected rather than transmitted. These electrons are detected as noise by the microscope and restrict the visual range to fibers with a diameter of about 0.20 μm or larger (Environmental Protection Agency, 1985b).

At present, there is no standard method, no quality assurance laboratory testing, and no National Institute of Science and Technology (NIST, formerly NBS) reference materials for SEM. In spite of this, SEM is still more available and much less expensive than TEM.

TRANSMISSION ELECTRON MICROSCOPY (TEM)

Transmission electron microscopy (TEM) is considered the better of the two types of electron microscopy used for measuring airborne asbestos. There are two methods for collecting fibers and preparing slides for TEM analysis. One method requires the collection of fibers on a 0.4 μm pore size polycarbonate filter. A strip of the polycarbonate filter is carbon coated, placed on a TEM grid, and cleared by Jaffe washer or condensation washer. The second method requires the collection of fibers on a 0.45 μm pore size cellulose ester filter. A wedge of the cellulose ester filter is collapsed on a glass slide, etched in a low temperature plasma asher, carbon coated, and transferred to a TEM grid using a Jaffe washer. By both methods, the mounted fibers are identified as asbestos (from fiber morphology, selected area electron diffraction (SAED) patterns, and energy dispersive x-ray analysis (EDXA), measured, and counted at 20,000x magnification (U.S. Environmental Protection Agency, 1985b; Federal Register, 1987).

The major disadvantages of TEM are the cost and the time required for analysis. It is also less available than the other two methods. The analysis can be broken down into three levels to reduce cost and time for analysis: (1) identification of asbestos (for screening purposes), (2) elemental analysis of selected fibers (for regulatory action), and (3) quantitative analysis of a few representative fibers (for confirmatory analysis) (Yamate et al., 1984; Federal Register, 1987).

FIBROUS AEROSOL MONITOR (FAM-1)

The fibrous aerosol monitor (FAM-1) is a real-time direct reading instrument for measuring airborne fibers. The detectability of fibers depends on both length and diameter. For example, fibers 5 μm long can be detected down to a diameter of about 0.75 μm; fibers 10 μm long can be detected down to a diameter of about 0.6 μm (Lilienfeld, 1987). The FAM-1 induces fibers to oscillate by means of an electric field and detects the light scattering signature resulting from the oscillation of the fibers under illumination by a helium-neon laser beam (Monitoring Instruments for the Environment, no date). This approach allows the counting of fibers in the presence of nonfibrous particles but does not discriminate between asbestos and non-asbestos fibers.

ORGANIC COMPOUNDS

OVERVIEW

A large number of organic compounds are typically present in indoor air. They range from compounds that are gases at ambient conditions to non-volatile compounds adsorbed onto suspended particulate material. Table 5 may be used to classify individual compounds on the basis of boiling point and provides information on typical sampling methods for each class. Most gas phase organic compounds may be measured by one or more of the general analytical methods described in the next section. More detailed information for specific compounds may be found in the literature (e.g., Riggin and Purdue, 1984; Riggin et al., 1986). Because of the emphasis placed upon them in the literature, formaldehyde, polycyclic aromatic hydrocarbons, and pesticides are covered in separate sections of this chapter.

GENERAL ANALYTICAL METHODS FOR GAS PHASE ORGANIC COMPOUNDS

Little is currently known about the concentrations and health risks of most organics in indoor air (Seifert and Ullrich, 1987). The Total Exposure Assessment Methodology (TEAM) Studies (Wallace, 1987; Pellizzari et al., 1987a,b; Handy et al., 1987), under the sponsorship of the U.S. EPA, represent the most in-depth studies of indoor pollutants to date. Personal air, fixed-site air, drinking water, and breath samples from individuals and homes in several states were analyzed for twenty selected organic chemicals, several of them carcinogenic. The methods used in the TEAM studies are rapidly becoming standard.

Emissions of specific organics from building materials and consumer products have been evaluated in the laboratory by various methods (Merrill et al., 1987; Wallace et al., 1987; Girman et al., 1987). Emissions from indoor combustion of fuels has also been studied (Traynor, 1987; Traynor et al., 1982; Spengler and Cohen, 1985).

As a rule, it is quite difficult to accurately measure a specific organic compound directly within the matrix of other components normally present in indoor air. The determination usually involves *collection* of a sample by some appropriate means, *separation* by gas chromatography, and *measurement* with an appropriate detector.

TABLE 5. CLASSIFICATION OF ORGANIC POLLUTANTS[a]

Description	Boiling Range[b] (°C)	Sampling Methods Used in Field Studies
Very Volatile Organic Compounds	<0 to 50-100	Batch sampling, adsorption on charcoal
Volatile Organ Compounds	50-100 to 240-260	Adsorption on tenax, carbon molecular black, or charcoal
Semi-Volatile Organic Compounds	240-260 to 380-400	Adsorption on polyurethane foam (PUF) or XAD-2
Particulate Organic Material[c]	>380	Collection on filters

[a]Adapted from World Health Organization (1987).
[b]Polar compounds tend to boil near the higher end of the range; less-polar compounds, near the lower end.
[c]Includes organic compounds associated with particulate matter.

Collection. Samples may be collected on a sorbent, in an impinger solution, or in an evacuated canister. Sorbent and impinger collection are more selective than canister collection although all methods have inherent disadvantages (Jayanty, 1989).

Ideally, a sorbent used for sample collection will have a strong affinity for the compound(s) of interest and little or no affinity for other species (H_2O, CO_2, etc.) in the matrix. Properties of several common sorbents are given in Table 6 (Sheldon et al., 1985; Raymer and Pellizzari, 1987; Levins, 1979; Krost et al., 1982; Piecewicz et al., 1979; Sanchez et al., 1987; Raymond and Guiochon, 1975; Riggin, 1984).

TABLE 6. PROPERTIES OF SOME COMMON SORBENTS

Sorbent	Properties
Tenax GC Resin	Porous polymer of 2,6-diphenyl-p-phenylene oxide; hydrophobic; not suitable for very light organics; lower capacity than XAD-2 but may be thermally desorbed.
XAD-2 Resin	A polystyrene-divinylbenzene porous polymer; hydrophobic; not suitable for very light organics; higher capacity than Tenax GC but requires solvent desorption.
Activated Charcoal	Typically a coconut charcoal; relatively high retention of water; organics are very strongly adsorbed; requires solvent desorption.
Graphitized Carbon Black	Obtained by heating thermal carbon blacks at 3000°C under an inert gas; nonselective; low retention of water and light gases; may be thermally desorbed.
Carbon Molecular Sieves	Pyrolyzed porous beads of polyvinylidene chloride; low capacity for water but organics are very strongly adsorbed; higher capacity for organics than graphitized carbon blacks; better than Tenax GC for highly volatile compounds; very light, volatile compounds may be thermally desorbed.

Sorbents offer the advantage of concentrating the sample as it is collected but require a desorption step prior to measurement. Desorption may be accomplished thermally or with a suitable solvent.

Impinger collection concentrates the analyte of interest through use of an absorbing solution. Impinger collection may also be used to stabilize very reactive substances, perhaps through derivatization.

Alternatively, samples may be collected in evacuated canisters. The inside walls of the canister must be chemically and physically inert to the species of interest. Stainless steel canisters with specially treated interior walls are available. Samples may also be collected in glass bulbs or bags made of an appropriate material (Jayanty, 1989).

Separation. Separation of organic gases and vapors is generally accomplished by gas chromatography (GC). Typically, a open-bore capillary column is used for the separation. The method is simple and relatively fast, and the species of interest can be measured as it exits the GC column by use of an appropriate detector. Cryogenic focusing or sorbent trapping may be used in the inlet of the GC to concentrate the sample and lower the detection limit for the species of interest.

Measurement. Gas chromatography detectors represent the most commonly used measurement method for airborne organics. Mass spectrometry, often associated with gas chromatography (GC-MS), is also used. A more recent approach involves the use of an array of sensors to selectively detect and measure a specific compound within the matrix (i.e., without separation).

Choice of an appropriate GC detector depends upon response to the compound(s) of interest, response to other species in the sample matrix, and desired sensitivity. Table 7 summarizes key features of some commonly used GC detectors.

Mass spectrometry (MS) provides one of the most powerful tools of chemical analysis. Every vaporizable compound gives a unique, often complex mass spectrum. Mass spectrometers used to measure components of complex mixtures must be used either (1) downstream from a gas chromatograph or (2) in conjunction with a sophisticated data system. Chemical ionization, rather than electron impact ionization, may be used to reduce fragmentation and simplify the mass spectrum, but the quantity of data acquired from a single analysis of a mixture is quite large.

An array of piezoelectric quartz crystals, each coated with a different partially selective material, may be used for direct analysis of multicomponent mixtures (Carey and Kowalski, 1986, 1988; Carey et al., 1987). The response of the array to a particular analyte resembles a typical absorption or emission spectrum with the resolution dependent on the number of sensors in the array. The pattern of the response is used to identify the analyte; analyte concentration is calculated from the magnitude of the response.

FORMALDEHYDE

Formaldehyde, because of its reactivity, is often collected in an impinger containing water. Formaldehyde reacts on contact with water to form methylene glycol. The water

TABLE 7. COMMON GAS CHROMATOGRAPHY DETECTORS

Detector	Detection Limit	Applications
Argon Ionization Detector	sub ppm to ppb	Responds to compounds with an ionization potential < 11.8 eV
Electron Capture Detector	pg	Responds to electron-capturing species, especially to halogenated compounds
Flame Ionization Detector	sub ppm sub ng	Responds to all combustible substances
Flame Photometric Detector	≥ sub ppb	Responds to compounds containing sulfur or phosphorus
Far Ultra-Violet Detector	low ng	Responds to all substances except the noble gases
Hall Electrolytic Conductivity Detector	50-100 pg	Responds to compounds containing a halogen, nitrogen or phosphorus
Helium Ionization Detector	sub ppm to ppb	Responds to compounds with an ionization potential < 19.8 eV
Mass Selective Detector	10 pg	Responds to all substances; may be used to identify as well as measure individual components of a mixture

TABLE 7 (cont'd). COMMON GAS CHROMATOGRAPHY DETECTORS

Detector	Detection Limit	Applications
Nitrogen Phosphorus Detector	10 pg	Responds to compounds containing nitrogen or phosphorus
Photo-Ionization Detector	10 pg ≥ ppb	Responds to compounds with an ionization potential < 11.7 eV
Redox Chemiluminescence Detector	sub ng	Responds to compounds containing oxygen, sulfur, nitrogen or phosphorus and to unsaturated hydrocarbons
Thermal Conductivity Detector	< 100 ppm	Responds to all compounds

solution is then treated with either chromotropic acid or pararosaniline and the resulting solution analyzed spectrophotometrically (National Research Council, 1981; Hawthorne and Matthews, 1987; Georghiou et al., 1987).

Diffusion badges containing a water solution may also be used to sample formaldehyde in air. After exposure, the badge solution is analyzed colorimetrically. A comparison of impinger and diffusion badge collection (Stock, 1987) indicates close agreement of the two sampling methods.

Silica gel coated with acidified 2,4-dinitrophenylhydrazine may be used to sample aldehydes and ketones in air (Tejada, 1986). Analysis of the sample, which contains the hydrazone derivatives of any aldehydes and ketones collected, is typically accomplished by high performance liquid chromatography (HPLC).

POLYCYCLIC AROMATIC HYDROCARBONS

Polycyclic aromatic hydrocarbons (PAHs) in air may (1) exist as a vapor, (2) be adsorbed onto atmospheric particulate material, or (3) be distributed between the vapor and adsorbed states. Sampling usually involves the collection of particulate-bound material on a filter and the collection of vapors on an adsorbent or in an impinger (Davis et al., 1987, and Otson et al., 1987).

The particulate-bound PAHs are typically extracted with a liquid solvent or a supercritical fluid (Hawthorne and Miller, 1987). Recovery is complicated by the vaporization of loosely bound PAHs from the particulate material after collection and by the difficulty of desorbing very tightly bound PAHs (Engelbach et al., 1987). Spitzer (1982) has shown that XAD-2 resin will separate PAHs from polar and non-polar contaminants in air particulate material. Extracts are usually analyzed by ultraviolet absorptiometry, fluorescence spectrometry, or gas chromatography/mass spectrometry, but a number of other methods have also been reported (Davis et al., 1987).

PESTICIDES

Carcinogenic species used in pesticides and frequently found in indoor air include chlordane, heptachlor/heptachlor epoxide, aldrin, and dieldrin (Cavender et al., 1986 and 1987). These and similar species are typically collected on polyurethane foam (PUF) or PUFin combination with some granular sorbent (e.g., XAD-2, Tenax GC, or Florisil PR). Following Soxhlet extraction and concentration, the samples are analyzed by GC-ECD, GC-MS, or GC-MS-MID (multiple ion detection) (Hsu et al., 1988; Lewis and Jackson, 1982; Lewis and MacLeod, 1982; Lewis et al., 1986).

INORGANIC SPECIES

OVERVIEW

In addition to asbestos, a number of inorganic pollutants, especially some of the heavy metals, have been classified as carcinogens. The inorganic species of most concern are inorganic arsenic (salts, arsenates, and arsenites); beryllium; cadmium (oxide, bromide, and chloride); chromium (hexavalent); nickel (carbonyl and subsulfide); and selenium (sulfide).

Table 8 summarizes sampling and analysis approaches that are currently used to measure concentrations of individual metals in workplace atmospheres. They should also be appropriate for indoor air. In most instances, more accurate methods of collection and analysis are available, but they have not yet been accepted as standard methods.

INORGANIC ARSENIC (SALTS, ARSENATES, AND ARSENITES)

National Institute for Occupational Safety and Health Method 7300 (Eller, 1984) is appropriate for 29 elements including arsenic. By this method, the sample is collected on a cellulose ester membrane filter and, after preparation, analyzed by inductively coupled argon plasma, atomic emission spectroscopy.

NIOSH Method 7900 is designed to measure arsenic and its compounds as arsenic. By this method, the sample is again collected on a cellulose ester membrane but, after preparation, is analyzed by atomic absorption, flame arsine generation. The estimated limit of detection for this method is 0.02 μg per sample (Eller, 1984).

BERYLLIUM

Beryllium occurs in air as a component of suspended particulate matter and may be collected on a membrane filter. Analysis by gas chromatography (Ross and Sievers, 1972) or atomic absorption spectroscopy (AAS) (Owens and Gladney, 1975) appears to offer adequate sensitivity, but both require pretreatment to remove interfering species (U.S. Environmental Protection Agency, 1987). Beryllium may also be measured by inductively coupled plasma emission.

TABLE 8. SAMPLING AND ANALYSIS APPROACHES FOR INORGANIC SPECIES

Species	Sampling	Analysis	LOD	Ref.
Arsenic (salts, arsenites, arsenates)	Cellulose ester membrane	ICAP-AES		a
		AA-Flame Arsine Generation	0.02 μg	a
	Membrane filter	GC		d,e
		AAS		d,f
Beryllium	Cellulose ester membrane	ICAP-AES		a
		AA-Graphite Furnace	0.05 μg	a
Cadmium (oxide, bromide, chloride)	Cellulose ester membrane	ICAP-AES		a
		AAF		a
		IC		b
	Filter	Effect on Oxid. of I^- by H_2O_2	0.001 μg	g
Chromium(VI)	Cellulose ester membrane	ICAP-AES		a
	PVC filter	VAS	0.05 μg	a
Nickel carbonyl	Impinger	Chemiluminescence	ppb	h
	Filter	AAF	0.005 μg/mL	i,j
Nickel subsulfide		AAS, XRF, ICAP, colorimetry, SSMS, NAA, FES		c
	Cellulose ester membrane	ICAP-AES	1 μg	a
Selenium sulfide	Cellulose ester membrane	ICAP-AES	1 μg	a

[a]Eller (1984)
[b]U.S. Environmental Protection Agency (1984)
[c]U.S. Environmental Protection Agency (1985a)
[d]U.S. Environmental Protection Agency (1987b)
[e]Ross and Sievers (1972)
[f]Owens and Gladney (1975)
[g]Kneebone and Freiser (1975)
[h]Stedman et al. (1979)
[i]Pickett and Koirtyohann (1969)
[j]Sachdev and West (1970)

Beryllium concentration may also be determined by NIOSH Method 7300, described above for arsenic, or by NIOSH Method 7102. Method 7102 requires collection on a cellulose ester membrane filter and, after sample preparation, analysis by atomic absorption, graphite furnace. The estimated limit of detection is 0.005 μg per sample (Eller, 1984).

CADMIUM (OXIDE, BROMIDE, AND CHLORIDE)

Cadmium may be analyzed by NIOSH Method 7300, described above for arsenic, or by NIOSH Method 7048. By Method 7048, the sample is collected on a cellulose ester membrane filter and, after preparation, analyzed by atomic absorption with flame. The estimated limit of detection by this method is 0.05 μg per sample (Eller, 1984).

CHROMIUM (HEXAVALENT)

Chromium occurs in air as a component of suspended particulate matter and may be collected on a filter. Filters are typically composed of cellulose, polyethylene, polystyrene, PVC, or glass (U.S. Environmental Protection Agency, 1984). Chromium(VI) may be separated from matrix materials by ion chromatography.

Chromium(VI), collected on filters, may be measured by a catalytic method developed by Kneebone and Freiser (1975). The measurement is based on the catalytic effect of chromium(VI) on the oxidation of iodide by hydrogen peroxide. The sensitivity of the method is 0.001 μg Cr(VI).

Chromium may also be measured by NIOSH Method 7300 as described previously for arsenic. Hexavalent chromium may be measured using NIOSH Method 7600 which requires sample collection on a PVC membrane filter and, after preparation, analysis by visible absorption spectrophotometry. The estimated limit of detection for this method is 0.05 μg per sample (Eller, 1984).

NICKEL (CARBONYL AND SUBSULFIDE)

Trace amounts of nickel in ambient air are almost always present as a component of suspended particulate matter. As a result, nickel is usually collected, along with other particulate material, on a filter. Unfortunately, nickel carbonyl, because of its volatility,

cannot be collected in this fashion. In sampling nickel from flue gases, an impinger is typically used to trap gaseous species (U.S. Environmental Protection Agency, 1985a).

The most commonly used analytical method for nickel in air is atomic absorption spectrophotometry with flame (AAF). The detection limit for nickel by this method is 0.005 μg/mL (Pickett and Koirtyohann, 1969; Sachdev and West, 1970). Other methods include atomic absorption spectrophotometry without flame, x-ray fluorescence spectrometry (XRF), inductively coupled argon plasma (ICAP) spectroscopy, colorimetry, spark source mass spectrometry (SSMS), neutron activation analysis (NAA), and flame emission spectrophotometry (FES) (U.S. Environmental Protection Agency, 1985a).

Analysis for specific nickel compounds in ambient air is quite difficult due to induced chemical changes inherent in the analytical techniques and to the very low concentrations of nickel compounds in ambient air. A variety of techniques for identifying compound form have been attempted on flyash samples (U.S. Environmental Protection Agency, 1985a).

Vapor-phase inorganic nickel compounds (e.g., nickel carbonyl) are easily separated from other nickel compounds on the basis of their volatility. The chemiluminescence analytical method is quite specific for nickel carbonyl and has a detection limit in the parts-per-billion range (Stedman et al., 1979).

Nickel may also be measured by NIOSH Method 7300 as described previously for arsenic. The estimated instrumental limit of detection for nickel is 1 μg per sample (Eller, 1984).

SELENIUM (SULFIDE)

Selenium may be measured by NIOSH Method 7300 as described previously for arsenic. The estimated instrumental limit of detection for selenium is 1 μg per sample (Eller, 1984).

PARTICLES

OVERVIEW

Particulate matter is made up of solid aerosols (e.g., dusts and smokes) and liquid aerosols (e.g., mists and fogs). Table 9 gives brief descriptions of devices used to collect and measure particles. Environmental tobacco smoke is perhaps the most notorious of the pollutants containing particulate material that may be present in indoor air.

ENVIRONMENTAL TOBACCO SMOKE

Environmental tobacco smoke (ETS) is a complex mixture of gaseous substances and suspended particulates and is quite difficult to measure in indoor air. More than 4,500 compounds have been identified in tobacco smoke: Some exist completely in the vapor phase, others are adsorbed onto particulate material, and still others are distributed between the vapor and adsorbed phases. As a result of adsorption onto and desorption from suspended particles, and even some chemical changes in the more reactive compounds, the components of ETS show a pronounced spatial and temporal distribution in indoor environments. In addition, background indoor air is a complex mixture containing a number of the chemical species also found in ETS. Even though body burden of specific components of ETS can be determined, there are no direct measures of total dose. However, there are several methods for assessing exposure.

Respirable suspended particle concentrations have been determined using personal monitors in order to estimate exposure to ETS (Spengler et al., 1985). In addition, personal and indoor space monitoring have been used to measure concentrations of specific compounds or classes of compounds and these (e.g., nicotine) may be used to indicate exposure to ETS (Hammond et al., 1987; Muramatsu et al., 1984). Two recent studies on the chemical composition of ETS suggests potential gas-phase (Eatough et al., 1989) and particulate phase (Benner et al., 1989) tracers based on environmental chamber experiments.

Sampling of ETS components may be active or passive. Active samplers utilize filters and/or vapor traps to collect material; passive samplers utilize diffusion and permeation to concentrate collected gases and vapors. In both cases, the samples are subsequently analyzed in the laboratory. Particles are typically measured by light-scattering principles or frequency

changes induced in piezoelectric quartz crystals. Gases are typically measured using infrared absorption, electrochemical reactions, or gas chromatography with appropriate detection (National Research Council, 1986; Hammond et al., 1987). Studies found in the literature (described in Guerin et al., 1987) suggest that determination of a specific compound (nicotine, for example) in ETS should include measurements of the quantity/concentration of the compound in both particle-bound and vapor- phase material (Hammond et al., 1987) since, as cigarette smoke ages some compounds change from particulate to vapor phase and vice versa.

Other approaches used to assess exposure to ETS include measuring air and body nicotine and cotinine, and nitrosamines: questionnaires; and exposure modeling. These topics are described in a later section of this work.

TABLE 9. SAMPLING DEVICES AND ANALYSIS METHODS FOR PARTICLES[a]

Device or Method	Description
Sampling Devices:	
settling chamber	Particles from a trapped sample of air settle by gravity onto a microscope slide.
centrifugal device	Centrifugal force, inside a small cyclone or curved surface trap, is used to separate particles on the basis of size.
impinger	A glass nozzle submerged in a liquid is used to collect particles.
impactor	Particles are collected from an aerosol stream by impaction onto a surface.
filter	Particles are collected by passing an air sample through a filter.
electrostatic precipitator	An ionizing electrode and a collection (or grounded) electrode are used to collect particles.
thermal precipitator	Particles are removed from an aerosol on the basis of response to a temperature gradient.
Analysis Methods:	
microscopy	Allows previously collected dust particles to be counted, sized, and/or identified.
piezoelectric	Allows real-time monitoring of particulate mass concentration by deposition of particles onto a quartz crystal.
optical	Allows a direct measurement of particles in air on the basis of particle interactions with light.
electrical	Allows direct measurement of particles in air on the basis of the tendency of airborne particles to acquire electrical charge.
beta attenuation	The collected mass of airborne particles is measured by its attenuation of beta radiation passing through it.

[a]Based on Lioy and Lioy (1983).

NON-IONIZING RADIATION

OVERVIEW

Non-ionizing radiation (NIR) refers to electromagnetic radiation with wavelengths longer than 100 nm. It includes ultra-violet (UV); visible; infrared (IR); radiofrequency (RF), including microwaves (MW); and extremely low frequency (ELF) fields, including power frequencies of 50-60 Hz. Pressure waves (e.g., infrasound and ultrasound) are also included (International Radiation Protection Association, 1985).

All electromagnetic radiation consists of an electric field and a magnetic field. Either or both, or their effects on living tissues, may be measured. The analytical approach used to measure NIR depends upon the purpose of the measurement. Radiometry deals with quantities (e.g., field intensity) associated with radiation fields; interaction coefficients deal with the interaction of radiation and matter; and dosimetry deals with quantities used to determine the specific absorption rate (SAR) of biological tissue (International Radiation Protection Association, 1985).

RADIOMETRIC MEASUREMENTS

Electric and magnetic fields associated with radiation of a particular wavelength oscillate at the same frequency, typically 50 or 60 cycles per second from alternating-current (AC) power lines. The fields have both a magnitude and a direction. The field intensity, or field strength, of an electric field is typically measured in volts per meter; the field intensity of a magnetic field, in teslas or gauss (Shepard et al., 1987).

The Electric Power Research Institute (EPRI) has funded the development of EMDEX (Electric and Magnetic Field Digital Exposure), a compact, lightweight instrument used to monitor personal exposure to electromagnetic radiation. Exposure assessments are obtained by combining the field intensity measurements and computer models which can extrapolate measured values to a wide variety of environments (Sussman, 1988; Shepard et al., 1987).

Cahill and Elder (1984) have described several other instruments, both developmental and commercial, for measuring the intensity of electric and magnetic fields.

INTERACTION COEFFICIENTS

Interactions of NIR with matter include attenuation, absorption, scattering, and reflection and related phenomena. An interaction coefficient may be calculated for each type of interaction (e.g., a scattering coefficient). The term "coefficient" generally refers to the relative decrease of a radiometric quantity due to an interaction phenomenon during passage through a thin layer of medium divided by the thickness of the layer. Interaction coefficients are expressed in reciprocal meters (m^{-1}) (International Radiation Protection Association, 1985).

DOSIMETRY

Dosimetry is the quantification of the specific absorption rate (SAR) of a biological entity. The SAR is dependent on the configuration of the source, the physical characteristics of the exposed subject, the orientation of the exposed subject with respect to the source, and the frequency of the electromagnetic radiation. Determination of the SAR of tissues requires measurements with electric field probes, thermocouples, thermistors, fiber optic probes, thermography, and calorimetry. The appropriate method for a particular application depends upon the frequency range of the radiation, the type of subject or biological preparation, and whether distributive or whole-body average SAR is desired (Guy, 1987).

OTHER APPROACHES TO ASSESSING EXPOSURE

BIOLOGICAL MARKERS

The assessment of exposure to some pollutants may be made by analysis of physiological fluids. Biochemical methods may be used to obtain estimates of exposure based on the uptake of specific agents in body fluids.

Biological markers have been used to estimate exposure to environmental tobacco smoke (ETS). For example, The presence of nicotine and its major metabolite, cotinine, in biological fluids is entirely due to exposure to tobacco, tobacco smoke, or environmental tobacco smoke. The determination of nicotine and cotinine in the saliva, blood, or urine of active or passive smokers is done primarily by gas chromatography (GC) with a nitrogen-sensitive detector, or by radioimmunoassay (RIA). The GC method can be used to measure concentrations of nicotine as low as 1 ng/mL and concentrations of cotinine as low as 6 ng/mL in biological fluids. The radioimmunoassays for nicotine and cotinine represent a newer analytical method. The sensitivity of these assays is about 0.5 ng/mL for both nicotine and cotinine and has inter- and intra-assay variation of $\pm 5\%$ (Langone et al., 1973; Hill et al., 1983). The RIA method has been used by only a limited number of laboratories because it requires the synthesis of specific nicotine and cotinine derivatives for the generation of serum albumin conjugates and the raising of antibodies to these conjugates (Langone et al., 1973). The RIA method also requires careful drawing and handling of samples to avoid contamination.

Cotinine, the major metabolite of nicotine, offers several advantages as a biological marker for ETS exposure. Cotinine is specific for tobacco and its quantitation can be useful in gathering information from large populations of both smokers and non-smokers.

The use of cotinine as an indicator of side-stream smoke exposure in children has been studied by Greenberg et al. (1984). The study revealed a high correlation between the exposure of children at home to side-stream smoke and the levels of cotinine in their urine.

QUESTIONNAIRES

Questionnaires can be useful for the assessment of exposure to some pollutants (e.g., ETS). A questionnaire may be used, for example, to determine the physical characteristics of microenvironments within a home and the activity patterns of those living there. From this information, individuals may be classified with regard to broad categories of exposure (National Research Council, 1986). It is not a simple matter, however, to design questions which will elicit unambiguous replies and permit quantitative estimates of individual exposures.

EXPOSURE MODELING

Exposure modeling requires knowledge of the concentrations of air contaminants in all the microenvironments within a residence or work area and the time individuals spend in each of those microenvironments. Typically, a model must take into account generation rate, ventilation, infiltration, mixing, removal by adsorption onto surfaces, and volume of space in which exposure occurs. Models are particularly useful in making exposure estimates in situations where measured concentrations are not available.

REFERENCES

Benner, C. L., J. M. Bayona, F. M. Caka, H. Tang, L. Lewis, J. Crawford, J. D. Lamb, M. L. Lee, E. A. Lewis, L. D. Hansen, and D. J. Eatough, (1989), "Chemical Composition of Environmental Tobacco Smoke. 2. Particulate-Phase Compounds," Environ. Sci. Technol., Vol. 23, No. 6:688-699.

Cahill, D. F., and J. A. Elder, eds., (1984), Biological Effects of Radiofrequency Radiation, Report No. EPA-600/8-83 026F, Health Effects Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

Carey, W. P., K. R. Beebe, and B. R. Kowalski, (1987), "Multicomponent Analysis Using an Array of Piezoelectric Crystal Sensors," Anal. Chem., Vol. 59, No. 11:1529-1534.

Carey, W. P., and B. R. Kowalski, (1986), "Chemical Piezoelectric Sensor and Sensor Array Characterization," Anal. Chem., Vol. 58, No. 14:3077-3084.

Carey, W. P., and B. R. Kowalski, (1988), "Monitoring a Dryer Operation Using an Array of Piezoelectric Crystals," Anal. Chem., Vol. 60, No. 6:541- 544.

Cothern, C. R., and J. E. Smith, Jr., eds., (1987), Environmental Radon, Plenum Press, New York.

Davis, C. S., P. Fellin, and R. Otson, (1987), "A Review of Sampling Methods for Polyaromatic Hydrocarbons in Air," J. Air Pollut. Control Assoc., Vol. 37, No. 12:1397-1408.

Eatough, D. J., C. L. Benner, J. M. Bayona, G. Richards, J. D. Lamb, M. L. Lee, E. A. Lewis, and L. D. Hansen, (1989), "Chemical Composition of Environmental Tobacco Smoke. 1. Gas-Phase Acids and Bases," Environ. Sci. Technol., Vol. 23, No. 6:679-687.

Eller, P. M., ed., (1984), NIOSH Manual of Analytical Methods, 3rd Ed., Cincinnati, OH., U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health.

Engelbach, R. J., A. A. Garrison, E. L. Wehry, and G. Mamantov, (1987), "Measurement of Vapor Deposition and Extraction Recovery of Polycyclic Aromatic Hydrocarbons Adsorbed on Particulate Solids," Anal. Chem., Vol. 59, No. 20:2541-2543.

Gearo, J. R., Jr, H. M. Singletary, and D. F. Naugle, (1988), "The Growth of the National Radon Measurement Proficiency (RMP) Program," The 1988 Symp. on Radon and Radon Reduction Technol., Vol. II. EPA/600/9-89/006b. Research Triangle Park, NC, Environmental Protection Agency, Air & Energy Engineering Research Laboratory, 1-1 to 1-14.

Georghiou, P. E., L. Winsor, C. J. Shirtliffe, and J. Svec, (1987), "Storage Stability of Formaldehyde Solutions Containing Pararosaniline Reagent," Anal. Chem., Vol. 59, No. 19:2432-2435.

Girman, J. R., and A. T. Hodgson, (1987), "Considerations in Evaluating Emissions from Consumer Products," Atmospheric Environment, Vol. 21, No. 2:315-320.

Greenberg, R. A., N. J. Haley, R. A. Etzel, and F. A. Loda, (1984), "Measuring the Exposure of Infants to Tobacco Smoke: Nicotine and Cotinine in Urine and Saliva," N. Engl. J. Med., Vol. 310:1075-1078.

Guerin, M. R., C. E. Higgins, and R. A. Jenkins, (1987), "Measuring Environmental Emissions from Tobacco Combustion: Sidestream Cigarette Smoke Literature Review," Atmospheric Environment, Vol. 21, No. 2:291-297.

Guy, A. W., (1987), "Dosimetry Associated with Exposure to Non-Ionizing Radiation: Very Low Frequency to Microwaves," Health Physics, Vol. 53, No. 6:569-584.

Hammond, S. K., B. P. Leaderer, A. C. Roche, and M. Schenker, (1987), "Collection and Analysis of Nicotine as a Marker for Environmental Tobacco Smoke," Atmospheric Environment, Vol. 21, No. 2:457-462.

Handy, R. W., D. J. Smith, N. P. Castillo, C. M. Sparacino, K. Thomas, D. Whitaker, J. Keever, P. A. Blau, L. S. Sheldon, K. A. Brady, R. L. Porch, J. T. Bursey, E. D. Pellizzari, and L. Wallace, (1986), Standard Operating Procedures Employed in Support of an Exposure Assessment Study, Volume IV; Air, Toxics, and Radiation Monitoring Research Division; Office of Monitoring, System and Quality Assurance; U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC 20460.

Hawthorne, A. R., and T. G. Matthews, (1987), "Models for Estimating Organic Emissions from Building Materials: Formaldehyde Example," Atmospheric Environment, Vol. 21, No. 2:419-424.

Hawthorne, S. B., and D. J. Miller, (1987), "Extraction and Recovery of Polycyclic Aromatic Hydrocarbons from Environmental Solids Using Supercritical Fluids," Anal. Chem., Vol. 59, No. 13:1705-1708.

Henschel, D. B., (1988), Radon Reduction Techniques for Detached Houses: Technical Guidance (Second Edition), EPA/625/5-87/019, Air and Energy Engineering Research Laboratory, Office of Environmental Engineering and Technology Demonstration, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711; Revised.

Hill, P., N. J. Haley, and E. L. Wynder, (1983), "Cigarette Smoking: Carboxyhemoglobin, Plasma Nicotine, Cotinine and Thiocyanate Levels vs. Self-reported Data and Cardiovascular Disease," J. Chron. Dis., Vol. 36:439-449.

Hsu, J. P., Wheeler, H.G., Jr., D. E. Camann, H. J. Schattenberg, III, R. G. Lewis, and A. E. Bond, (1988), "Analytical Methods for Detection of Nonoccupational Exposure to Pesticides," J. Chromatogr. Sci., Vol. 26:181- 189.

International Radiation Protection Association (1985), "Review of Concepts, Quantities, Units and Terminology for Non-Ionizing Radiation Protection: A report of the International Non-Ionizing Radiation Committee of the International Radiation Protection Association," Health Physics, Vol. 49, No. 6.

Jayanty, R. K. M., (1989), "Evaluation of Sampling and Analytical Methods for Monitoring Toxic Organics in Air," Atmospheric Environment, Vol. 23, No. 4:777-782.

Kneebone, B. M., and H. Freiser, (1975), "Determination of Chromium(VI) in Industrial Atmospheres by a Catalytic Method," Anal. Chem., Vol. 47, No. 3:595-598.

Krost, K. J., E. D. Pellizzari, S. G. Walburn, and S. A. Hubbard, (1982), "Collection and Analysis of Hazardous Organic Emissions," Anal. Chem., Vol. 54, No. 4:810-817.

Kusnetz, H. L., (1956), "Radon Daughters in Mine Atmospheres--A Field Method for Determining Concentrations," Am. Ind. Hyg. Assoc. J., Vol. 17:85-88.

Langone, J. J., H. Gjika, and H. Van Vunakis, (1973), "Nicotine and Its Metabolites. Radioimmunoassays for Nicotine and Cotinine," Biochemistry, Vol. 12:5025-5030.

Levins, P. L., (1979), "The Use of Sorbent Resins in Environmental Sampling," Process Measurements Review, Vol. 1, No. 4:7-8, Spring Edition.

Lewis, R. G., and K. E. MacLeod, (1982), "Portable Sampler for Pesticides and Semivolatile Industrial Organic Chemicals in Air," Anal. Chem., Vol. 54, No. 2:310-315.

Lewis, R. G., and M. D. Jackson, (1982), "Modification and Evaluation of a High-Volume Air Sampler for Pesticides and Semivolatile Industrial Organic Chemicals," Anal. Chem., Vol. 54, No. 3:592-594.

Lewis, R. G., A. E. Bond, T. R. Fitz-Simons, D. E. Johnson, and J. P. Hsu, (1986), "Monitoring for Non-Occupational Exposure to Pesticides in Indoor and Personal Respiratory Air," Presented at the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, Minnesota, June 22-27, 1986, paper no. 86-37.4..

Lilienfeld, P., (1987), Asbestos Monitoring with the MIE Fibrous Aerosol Monitor, Monitoring Instruments for the Environment, Inc., 213 Burlington Road, Bedford, Massachusetts 01730.

Lioy, P. J., and M. J. Y. Lioy, eds., (1983), Air Sampling Instruments for Evaluation of Atmospheric Contaminants, 6th ed., American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio.

Merrill, R. G., R. S. Steiber, R. F. Martz, and L. H. Nelms, (1987), "Screening Methods for the Identification of Organic Emissions from Indoor Air Pollution Sources," Atmospheric Environment, Vol. 21, No. 2:331-336.

Monitoring Instruments for the Environment, Inc. (MIE) (no date), Fibrous Aerosol Monitor, MIE, Inc., 213 Burlington Road, Bedford, Massachusetts 01730.

Muramatsu, M., S. Umemura, T. Okada, and H. Tomita, (1984), "Estimation of Personal Exposure to Tobacco Smoke with a Newly Developed Nicotine Personal Monitor," Environ. Res., Vol. 35:218-227.

National Research Council, (1986), Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects, prepared by the Committee on Passive Smoking, Board on Environmental Studies and Toxicology, National Research Council; National Academy Press, Washington, D.C.

National Research Council, (1981), Formaldehyde and Other Aldehydes, Committee on Aldehydes, Board on Toxicology and Environmental Health Hazards, Assembly of Life Sciences, National Research Council; National Academy Press, Washington, D.C.

Otson, R., J. M. Leach, and L. T. K. Chung, (1987), "Sampling of Airborne Polycyclic Aromatic Hydrocarbons," Anal. Chem., Vol. 59, No. 13:1701-1705.

Owens, J. W., and E. S. Gladney, (1975), "Determination of Beryllium in Environmental Materials by Flameless Atomic Absorption Spectroscopy," At. Absorpt. Newsl., Vol. 14:76-77.

Pellizzari, E. D., K. Perritt, T. D. Hartwell, L. C. Michael, C. M. Sparacino, L. S. Sheldon, R. Whitmore, C. Leninger, H. Zelon, R. W. Handy, D. Smith, and L. Wallace, (1987a), Total Exposure Assessment Methodology (TEAM) Study: Elizabeth and Bayonne, New Jersey, Devils Lake, North Dakota, and Greensboro, North Carolina, Volume II, Final Report; Air, Toxics, and Radiation Monitoring Research Division; Office of Monitoring, System and Quality Assurance; U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC 20460.

Pellizzari, E. D., K. Perritt, T. D. Hartwell, L. C. Michael, R. Whitmore, R. W. Handy, D. Smith, H. Zelon, and L. Wallace, (1987b), Total Exposure Assessment Methodology (TEAM Study): Selected Communities in Northern and Southern California, Volume III, Final Report; Air, Toxics, and Radiation Monitoring Research Division; Office of Monitoring, System and Quality Assurance; U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC 20460.

Pickett, E. E., and S. R. Koirtyohann, (1969), "Emission Flame Photometry-- A New Look at an Old Method," Anal. Chem., Vol. 41:28A-42A.

Piecewicz, J. F., J. C. Harris, and P. L. Levins, Further Characterization of Sorbents for Environmental Sampling, Report No. EPA-600/7-79-216, sponsored by EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711.

Raymer, J. H., and E. D. Pellizzari, (1987), "Toxic Organic Compound Recoveries from 2,6-Diphenyl-p-phenylene Oxide Porous Polymer Using Supercritical Carbon Dioxide and Thermal Desorption Methods," Anal. Chem., Vol. 59, No. 7:1043-1048.

Raymond, A., and G. Guiochon, (1975), "The Use of Graphitized Carbon Black as a Trapping Material for Organic Compounds in Light Gases Before a Gas Chromatographic Analysis," J. of Chrom. Science, Vol. 13:173-177.

Research Triangle Institute (1988) National Radon Measurement Proficiency (RMP) Program, Analytical Proficiency Report, Round 5 Performance Test. Contract number 68-01-7350, U.S. Environmental Protection Agency

Riggin, R. M., (1984), "Evaluation of Carbon Molecular Sieves as Adsorbents for the Determination of Volatile Organic Compounds," presented at the APCA/ASQC Specialty Conference On: Quality Assurance in Air Pollution Measurements, Boulder, Colorado, October 14-18, 1984. Co-Sponsored by The Air Pollution Control Association and The American Society for Quality Control.

Riggin, R. M., and L. J. Purdue, (1984), Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, EPA-600/4-84-041; Quality Assurance Division, Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

Riggin, R. M., W. T. Winberry, Jr., N. V. Tilley, and L. J. Purdue, (1986), Supplement to EPA/600/4-84/041: Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, EPA/600/4-87-006; Quality Assurance Division, Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

Ross, W. D., and R. E. Sievers, (1972), "Environmental Air Analysis for Ultratrace Concentrations of Beryllium by Gas Chromatography," Environ. Sci. Technol., Vol. 6(2):155-158.
Sachdev, S. I., and P. W. West, (1970), "Concentration of Trace Metals by Solvent Extraction and Their Determination by Atomic Absorption Spectrophotometry," Environ. Sci. Technol., Vol. 4(9):749-751.

Samuelsson, C. (1988) "Retrospective Determination of Radon in Houses," Nature, Vol. 334:338-340.

Sanchez, D. C., M. Mason, and C. Norris, (1987), "Methods and Results of Characterization of Organic Emissions from an Indoor Material," Atmospheric Environment, Vol. 21, No. 2:337-345.

Seifert, B., and D. Ullrich, (1987), "Methodologies for Evaluating Sources of Volatile Organic Chemicals (VOC) in Homes," Atmospheric Environment, Vol. 21, No. 2:395-404.

Sheldon, L. S., C. M. Sparacino, and E. D. Pellizzari, (1984), "Review of Analytical Methods for Volatile Organic Compounds in the Indoor Environment," Indoor Air and Human Health, Proceedings of the Seventh Life Sciences Symposium, Knoxville, Tennessee, October 29-31, 1984, Chapter 26, pp. 335-349.

Shepard, M., L. Sagan, R. Black, S. Sussman, and C. Rafferty, (1987), "EMF: The Debate on Health Effects," EPRI Journal, pp. 4-15, October/November 1987.

Singletary, H. M., (1988), Coordinator, Natural Radionuclide Programs, Research Triangle Institute, Research Triangle Park, NC 27709; unpublished summary.

Spengler, J. D., R. D. Treitman, T. D. Tosteson, D. T. Mage, and M. L. Soczek, (1985), "Personal Exposures to Respirable Particulates and Implications for Air Pollution Epidemiology," Environ. Sci. Technol., Vol. 19:700-707.

Spengler, J. D., and M. A. Cohen, (1985), "Emissions from Indoor Combustion Sources," Indoor Air and Human Health, Proceedings of the Seventh Life Sciences Symposium, Knoxville, Tennessee, October 29-31, 1984, Chapter 20, pp. 261-278.

Spitzer, T., (1982), "Clean-Up of Polynuclear Aromatic Hydrocarbons from Air Particulate Matter on XAD-2," J. of Chrom., No. 237:273-278.

Stedman, D. H., D. A. Tammaro, D. K. Branch, and R. Pearson, Jr. (1979), "Chemiluminescence Detector for the Measurement of Nickel Carbonyl in Air," Anal. Chem., Vol. 51:2340-2342.

Stock, T. H., (1987), "Formaldehyde Concentrations Inside Conventional Housing," J. Air Pollut. Control Assoc., Vol. 37, No. 8:913-918.

Sussman, S. S., (1988), "Electric and Magnetic Field Exposure Assessment," EPRI Journal, pp. 50-52.

Tejada, S. B., (1986), "Evaluation of Silica Gel Cartridges Coated In Situ with Acidified 2,4-Dinitrophenylhydrazine for Sampling Aldehydes and Ketones in Air," Intern. J. Environ. Anal. Chem., Vol. 26, pp.167-185.

Traynor, G. W., M. G. Apte, J. F. Dillworth, C. D. Hollowell, and E. M. Sterling, (1982), "The Effects of Ventilation on Residential Air Pollution Due to Emissions from a Gas-Fired Range," Environment International, Vol. 8:447-452.

Traynor, G. W., (1987), "Field Monitoring Design Considerations for Assessing Indoor Exposures to Combustion Pollutants," Atmospheric Environment, Vol. 21, No. 2:377-383.

Tsviglou, E. G., H. E. Ayers, and D. A. Holaday, (1953), "Occurrence of Nonequilibrium Atmospheric Mixtures of Radon and Daughters," Nucleonics, Vol. 11:40.

U.S. Environmental Protection Agency, (1984), Health Assessment Document for Chromium, EPA/600/8-83-014F, Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

U.S. Environmental Protection Agency, (1985a), Health Assessment Document for Nickel, EPA/600/8-83/012F, U.S. Environmental Protection Agency, Office of Research and Development, Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Research Triangle Park, NC 27711.

U.S. Environmental Protection Agency, (1985b), Measuring Airborne Asbestos Following An Abatement Action, EPA 600/4-85/049, Quality Assurance Division, Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, and Exposure Evaluation Division, Office of Toxic Substances, Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency, Washington, DC 20460.

U.S. Environmental Protection Agency (1986), Carcinogenicity Assessment of Chlordane and Heptachlor/Heptachlor Epoxide, EPA/600/6- 87/004, Carcinogen Assessment Group, Office of Health and Environmental Assessment, Office of Research and Development, Washington, D.C.

U.S. Environmental Protection Agency, (1987a), "Asbestos-Containing Materials in Schools; Final Rule and Notice," Federal Register, Part III, Environmental Protection Agency, 40 CFR Part 763.

U.S. Environmental Protection Agency, (1987b), Health Assessment Document for Beryllium, EPA/600/8-84/026F, U.S. Environmental Protection Agency, Office of Research and Development, Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Research Triangle Park, NC 27711.

U.S. Environmental Protection Agency (1987a), Carcinogenicity Assessment of Aldrin and Dieldrin, EPA/600/6-87/006, Carcinogen Assessment Group, Office of Health and Environmental Assessment, Office of Research and Development, Washington, D.C.

U.S. Environmental Protection Agency, (1988), Radon Measurement Proficiency Program Application and Participation Manual, EPA-520/1-87-022, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC 20460.

Wallace, L. A., (1986), The Total Exposure Assessment Methodology (TEAM) Study: Summary and Analysis, Volume I, Final Report, Environmental Monitoring Systems Division, Office of Acid Deposition, Environmental Monitoring and Quality Assurance, U.S. Environmental Protection Agency, Office of Research and Development, Washington DC 20460.

Wallace, L. A., E. Pellizzari, B. Leaderer, H. Zelon, and L. Sheldon, (1987), "Emissions of Volatile Organic Compounds from Building Materials and Consumer Products," Atmospheric Environment, Vol. 21, No. 2:385-393.

WHO, (1987), "Working Group on Indoor Air Quality: Organic Pollutants Berlin (West) 23-28 August 1987," Draft Final Report, ICP/CEH 026.

Yamate, G., S. C. Agarwal, and R. D. Gibbons, (1984), Methodology for the Measurement of Airborne Asbestos by Electron Microscopy, Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

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